

The Effect of Small-Scale Ocean Fluctuations on Ocean Acoustic Transmission

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LONG-TERM GOALS

To understand the behavior of a scalar field propagating in a waveguide with inhomogeneous, anisotropic, small-scale structure. Oceanographically, to connect the results of sound transmission and scattering experiments to known or hypothesized structures within the hydrosphere, such as internal tides, internal waves, or microstructure, with account taken of ocean anisotropy, inhomogeneity, and the sound channel.

OBJECTIVES

To develop analytic and computer techniques for the calculation of sound fluctuations due to ocean structure, especially internal waves, and to use the parabolic-equation technique as a benchmark to which these and other calculational approaches can be compared. To compare the results of these techniques with experiment.

APPROACH

The path-integral technique for calculating sound fluctuations through internal waves in terms of line integrals along unperturbed rays was developed in the 70's and 80's. As computers grew more capable, it became possible to do these integrals for realistic cases, as well as to propagate through multiple realizations of internal waves using the parabolic equation, and to follow multi-thousands of geometrical-acoustics rays through realizations of internal waves. The approach used in this grant is to make use of these developments to compare different methods with each other, and with experiment.

WORK COMPLETED

A computer code (CAFI) was developed and completed within this grant to calculate the line integrals that are used in the path-integral technique to predict sound fluctuations from internal-wave fields that are homogeneous in range from source to receiver (<http://es.ucsc.edu/~smf/cafi/cafi.html>) [Flatté and Rovner, 2000]. Another code was completed within this grant that has been used to follow 160,000 rays through an internal-wave field in order to understand such matters as the development of microrays by the smallest-scale internal waves [Simmen, Flatté, and Wang, 1997]. A system for using the parabolic equation to calculate the sound field from a pulsed source as a function of range to 1000 km or more, in the presence of different strengths of the internal-wave field, and in different background sound-speed environments was developed in FY2002 by the PI and then-graduate-student

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Michael Vera (now at SIO/IGPP). The internal-wave sound-speed fluctuations in this system are created by a code developed by former graduate student John Colosi (now at WHOI) and Michael Brown of U. Miami [Colosi and Brown, 1997].

During FY2002 and 2003, an extensive effort was exerted by the PI and graduate student Michael Vera to use the system that propagates a sound pulse via the parabolic equation (PE) through internal waves to generate sound fields at each 100 km out to 1000 km. The code generates a timefront (intensity as a function of time and depth), which consists of many segments, each with an ID number for identification. The code was extended to use depth regions where the ID was unambiguous, and to find the arrival time for that ID at each depth for each realization. For each case of internal-wave strength and for each of two sound-speed profiles, 30 realizations of the internal-wave field were used, generating enough statistics to determine the rms travel-time, the vertical structure function of travel time, the average change in travel time due to internal waves (the bias), and the pulse width. These results for the fluctuations in sound were compared with results from the integral approximations (IA) calculated by the code described in [Flatté and Rovner, 2000].

Another effort during this year has been the writing, with co-author John Colosi, of a chapter in a planned book on Acoustic Propagation through Internal Waves, being edited by Lou Goodman, Ellen Livingston, and Jeff Simmen. The various chapters of this book are now being unified, but further work on this project is expected to continue.

RESULTS

The results from the comparison between the PE and the IA calculations out to 1000 km were published during this year [Flatté and Vera, 2003]. These are the first results ever published of highly quantitative comparisons between fluctuation quantities calculated from PE runs and from path-integral-derived IA evaluations, both through the same internal-wave field. In summary, the IA predictions for the rms travel time are in good agreement with those from the PE calculations, out to 1000 km. The rms vertical arrival angle (measured through the vertical structure function of travel time) of the IA results are about one-half of the value of the PE results. (See accompanying Figure.) However, the bias and the vertical coherence, although they agree out to 400 km, disagree substantially between 500 and 1000 km. Furthermore, the pulse widths (which were only compared at 1000 km) disagree, in that the IA predictions are an order-of-magnitude larger than the PE results. In the publication, reasons and analyses of these differences are made.

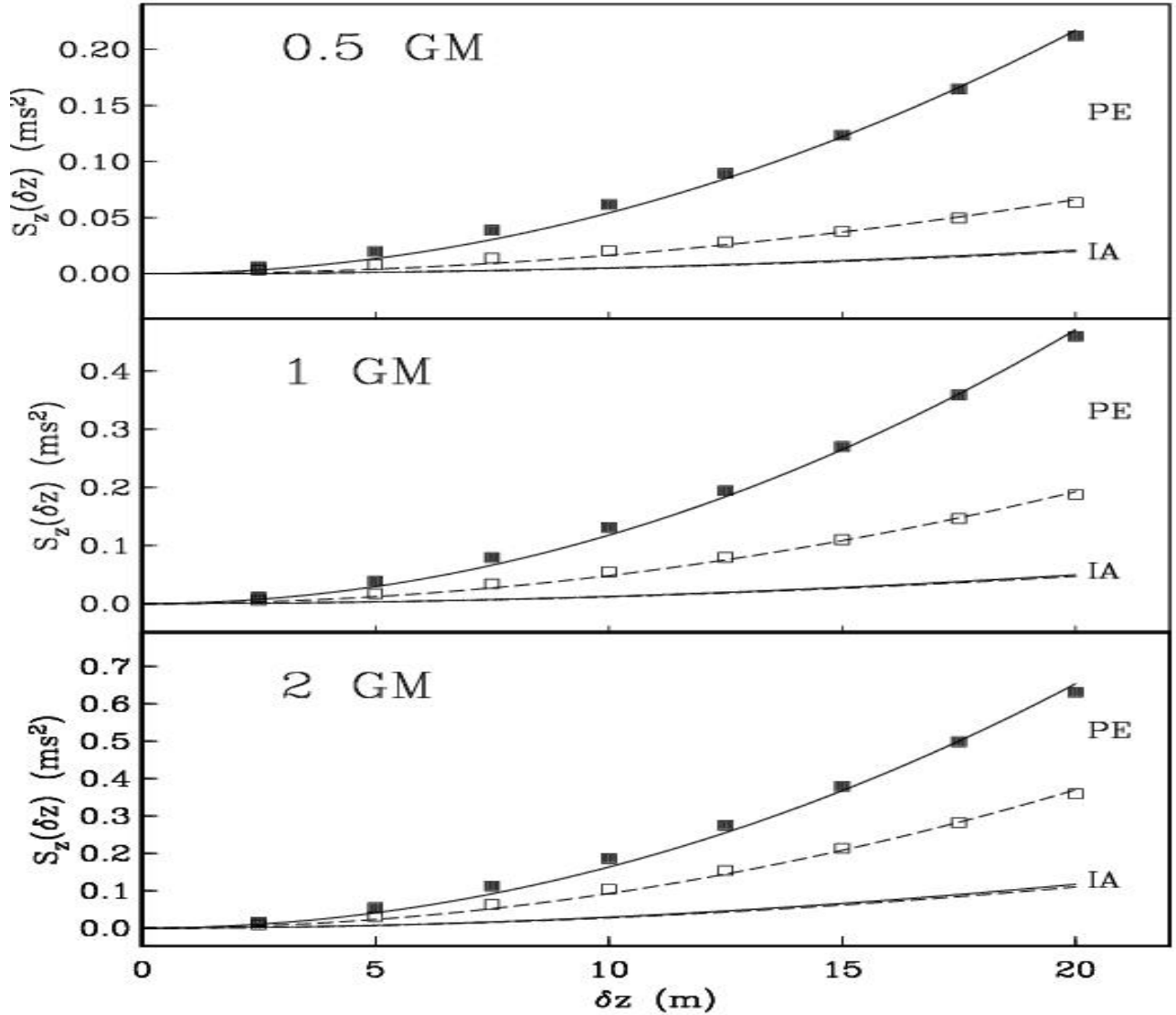


Figure Caption: The structure function of travel time $(t(z_1) - t(z_2))^2$ as a function of $t(z_1) - t(z_2)$ shows a clear quadratic behavior, which is expected from incoming plane waves with varying arrival angles. The three panels are from results with internal-wave spectrum strength of 0.5, 1.0, and 2.0 times the reference Garrett-Munk spectrum. The square points are from PE simulations (closed squares from a canonical sound-speed profile, and open squares from a profile from the Slice89 experiment). The lower lines are from the IA results; the results of the two quite different profiles fall on top of each other. The rms arrival angles from the IA results are about half of those from the PE results. It should be noted that the pulse width at each depth at 1000 km, for 2 GM, is of order 6 ms; the accuracy of the center of the pulse should be less than 0.6 ms. At smaller values of internal-wave strength, the accuracy of the pulse center should be substantially less. The fact that the curve approaches zero for the smallest depth separation (2.5 m) is a good indication that the pulse width is not a problem.

IMPACT/APPLICATIONS

Results from 5 years ago showed that the IA calculation of rms travel time should be valid out to multi-megameter ranges. Our new results are consistent with that, but now show that some of the statistics from the IA that probe the more detailed aspects of the sound propagation are not valid beyond 500 km. Therefore, either extensive use of the PE is needed, or different analytic treatment is required. Such a different analytic method is not available, but there are several that are being developed now that will need to be tested. Our system of finding sound fluctuations with the PE method can be used to evaluate any other method that is suggested. The first results from that system were published in [Flatté and Vera, 2003] and new methods could test against those results, initially without requiring further PE calculations.

TRANSITIONS

The CAFI code described in [Flatté and Rovner, 2000] and <http://es.ucsc.edu/~smf/cafi/cafi.html> has been transitioned to other scientists who are interested in sound propagation (including short-range, high-frequency propagation). The response of outside users is evidenced by several email correspondences with the people who need help in its use. This code is useful for any propagation in the 100-km region, as well as other ocean propagations. It can also be adapted to any wave propagation through a medium that involves inhomogeneity, anisotropy, and a uniform background waveguide. Examples of such waves and media are optical waves through atmospheric turbulence, seismic waves through the earth, and radio waves through the ionosphere or other plasmas.

RELATED PROJECTS

The PI collaborates with the experimental groups that created and analyzed the Slice89 (1000-km) and AET (3250 km) experiments, as well as the more recent NPAL experiment, including Peter Worcester, Michael Vera, and their co-workers at SIO, and John Colosi at WHOI. He also has continuing conversations with other theorists who are using various techniques to calculate aspects of acoustic propagation, such as John Colosi, Michael Brown, and Steven Tomosovic, from the University of Washington at Pullman.

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PUBLICATIONS

Stanley M. Flatté and Michael D. Vera. Comparison between ocean-acoustic fluctuations in parabolic-equation simulations and estimates from integral approximations, *J. Acoust. Soc. Am.* **114**(2):697-706 (August 2003)